S282 Astronomy

Sunspot number

Study time: 90 minutes

Summary

In this activity you will plot and analyse sunspot data covering a 50-year period. You should have read to the end of Section 1.2 of *An Introduction to the Sun and Stars* before doing this activity.

This is the first activity that requires the use of a spreadsheet. Before starting this activity you should ensure that you have an appropriate spreadsheet package installed on your computer – see the *Using Spreadsheets* guide on the course website for more details.

If you are already familiar with using spreadsheets you will be able to complete the activity in a shorter time than suggested.

Learning outcomes

- Use a spreadsheet to perform simple calculations and to display data by plotting graphs.
- Present information in a spreadsheet effectively, accurately and in a way that makes sense.
- Analyse graphical data in both qualitative and quantitative terms.
- Develop your understanding of the solar cycle.

Background to the activity

Sunspots

The surface of the Sun contains a number of features including granulation, plages and sunspots. Sunspots can be seen as dark patches against the solar photosphere. This darkness is relative: sunspots have a temperature of around 4200 K compared with the hotter photosphere (6000 K) and thus appear dark against the brighter background.

Individual sunspots have a fairly short life span of just a few weeks, but the *numbers* of sunspots have been observed to fluctuate on a regular cycle. This variation is correlated with the cycle in solar activity.

Detailed records of sunspot numbers have been kept since 1849 but historical accounts go back much further and provide a long-running continuous record of solar activity.

How sunspot numbers are computed today

In 1848 Rudolph Wolf (who went on to become director of the Zurich observatory) discovered the connection between the occurrence of sunspots and disturbances in the Earth's magnetic field. He also devised the modern convention for calculating a quantity that measures the number and extent of sunspots, the so-called *sunspot number*.

At times of high solar activity sunspots frequently occur in groups. To form the sunspot number the number of groups is multiplied by ten and added to the number of individual spots. Because the number of sunspots can vary as a result of the Sun's rotation and the location of observers, the overall figure is calculated as the average of all the counts made by a network of participating observatories. The resulting quantity is formally referred to as the Wolf number or Zurich number.

Records of the Wolf number have been kept since the mid-19th century. Using historical records, it has been possible to infer values of the Wolf number back to 1749.

WARNING

NEVER look at the Sun directly, not even with the naked eye and especially not through binoculars or a telescope even if fitted with filters. Permanent eye damage could result.

The activity

The aim of this activity is to produce a plot that shows how sunspot number has varied with time over the period 1953–2000, and to interpret this plot to estimate the period of the sunspot cycle. Much of the detailed description relates to the use of the spreadsheet package, but as you work through these notes you should bear in mind that the goal is to produce a chart that shows scientific information in a meaningful fashion.

The instructions given here assume that you will be using the StarOffice™ package that is supplied on the OU Online Applications CD-ROM. If you are already familiar with using another spreadsheet package (such as Microsoft Excel) you may want to use that to carry out the activity (we have supplied the required data file in Excel format). However, before starting you should be aware that these notes only give instructions on how to manipulate the StarOffice spreadsheet.

As you work through the examples feel free to experiment with the spreadsheet commands and menus. Don't worry if you make a mistake: in most cases you can use the key combination Ctrl-Z to undo the last action and bring you back to where you were before.

Before you start – create a folder for your work

In this activity you will be modifying a spreadsheet file and you will need to save this to your hard disk. Before you start it would be a good idea to create a folder in which you can store the results of your work.

Open the raw data file

The raw data for this activity is contained in a file called 'Sunspots_raw_data.sxc' (the Excel version of the file is called 'Sunspots_raw_data.xls').

- Start the S282 Multimedia guide program and open the folder called 'The Sun', then click on the icon for this activity ('Sunspot number').
- Press the Start button to access the folder on the DVD containing the StarOffice and Excel versions of the raw data file.
- Open the file you wish to use by double-clicking on it.

Save a copy of the file

Before you can make changes to the file you must save it to your hard disk.

- Use the File | Save as... menu command to save a copy of the spreadsheet into your work folder.

As you make changes to the spreadsheet you should save your work regularly to prevent any changes from being lost. From time to time make a *backup copy* of your work (using a different filename) in case you need to go back to an earlier stage. (If it all goes horribly wrong you can always go back to the original from the DVD!)

Formatting data

As the name implies, the spreadsheet you have just opened contains just the *raw* data of sunspot counts for each month over a period of nearly 50 years.

In order to turn this into a meaningful scientific document you will need to format this data, carry out some simple calculations on it, and plot a graph showing the variation in sunspot number over time. We will also review some of the important ideas about spreadsheets that are discussed in the *Using Spreadsheets* guide as we progress through this activity.

The spreadsheet is made up of a large number of cells arranged into *rows* and *columns*. Notice that along the top of spreadsheet the columns are labelled A, B, C, etc., and that down the left-hand edge of the spreadsheet, each row is numbered. Thus every cell on the sheet can be uniquely identified by its column label and its row number: this identification is called the *c*ell reference. For instance, the cell in the top left-hand corner of the sheet has a cell reference A1, the cell below it is A2 and the cell to the right of this is cell B2.

Each cell can contain either text or a number. Cells can also contain formulae that carry out calculations based on the contents of other cells. Normally a cell containing a formula will display the *result* of the calculation. Note that you can edit the formula itself in the input line – this is situated just above the top row of the sheet.

For more information, refer to the *Using Spreadsheets* guide.

Add titles

The raw data file that you have opened contains a list of years and months, and a column of numbers, but there is nothing to tell the reader what the data *are* or what they *mean*. (Don't forget that this may be yourself in a few months time, trying to remember what you did – so it pays to have everything clearly labelled and documented!). You are going to start by adding a heading and column titles to the spreadsheet.

Insert rows

To make room for the headings you need to create some blank lines above the data. At the left-hand side of each row there is a grey button labelled with the row number. Using the left mouse button, click on button 1 and then, holding down the left button, drag down to button 4, highlighting the first four rows.

Now right-click the mouse on any one of these four buttons. This will display a drop-down menu (Figure 1). Select Insert Rows from this menu to insert four blank rows. (You could also do this by selecting Insert | Rows from the main menu.) Notice that rows are inserted above the highlighted area and that the rows containing data are moved down.

Don't worry if it doesn't work exactly as you expected first time: remember, you can always use Ctrl-Z to undo the most recent change.

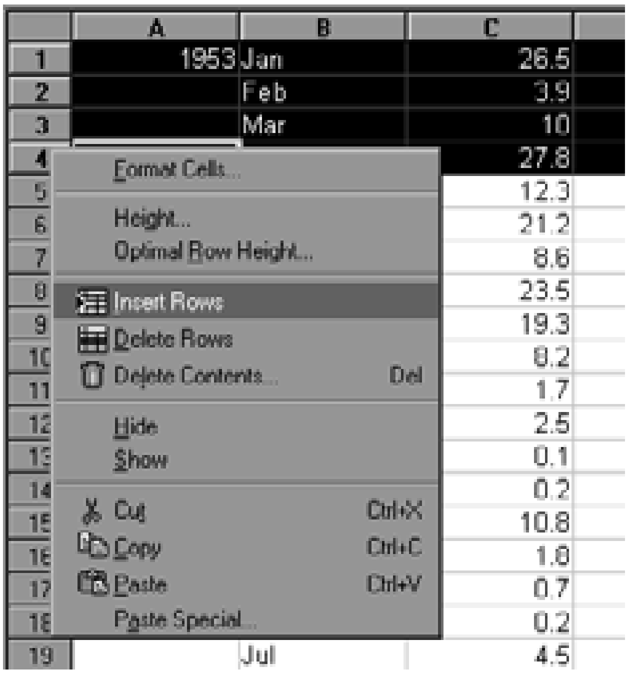


Figure 1 Inserting rows into the spreadsheet.

Enter spreadsheet titles

You are going to add a title in the top row of the spreadsheet.

- Select cell A1 by clicking it with the mouse. Notice that the cell is highlighted with a darker border, and the row '1' and column 'A' headings are also highlighted.
- Type in an appropriate heading, such as: 'Activity: Sunspot number'. As you type, notice that the text also appears in the input line directly above the top row of the spreadsheet. If you need to edit the contents of the cell at a later stage you can do so by selecting the cell and making the changes in this input line (alternatively you can double-click the cell and edit the contents directly). When you have finished typing press Enter (or click on another cell) to complete the entry.

  It is good practice to always record the source of any data that you work with. These data were obtained from the National Solar Observatory in the United States.
- Select cell A2 and insert an appropriate subtitle to describe the source of these data.

Format titles

The titles that we have added are OK, but the writing is quite small. We can improve the appearance of the spreadsheet by formatting the titles.

- Select cell A1 again. Increase the font size by selecting 20 from the Font Size box (located on the toolbar above columns A and B) (Figure 2). The whole of row 1 will increase in height. Similarly, increase the size of cell A2 to a font size of 14. This makes the headings easier to read.

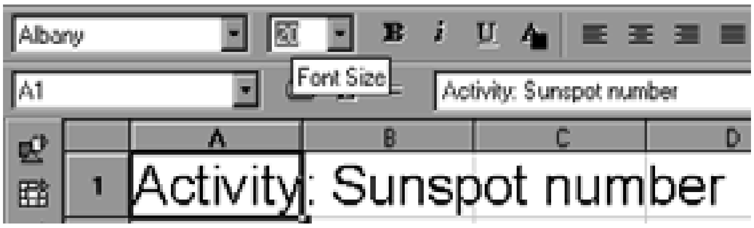


Figure 2 The font size box.

- Now select the whole of row 1 by clicking on the 1 button to the left of cell A1. Select Format | Cells ... from the main menu and choose a suitable colour from the Background tab. Do the same thing for row 2 (selecting a different colour if you wish).

Enter column headings

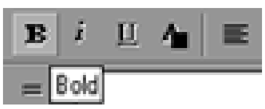
Now we need to include headings for each of the columns to explain what the data are.

- In cell A4 enter 'Year', in B4, 'Month' and in cell C4, 'Sunspot number'. You may have to increase the width of the sunspot number column – you can do this by selecting the cell C4 and then using Format | Column | Optimal width. Make sure the Default value option is not selected and then click on OK in the Optimal Column Width box that appears.
- Select all three cells (A4, B4 and C4) and select the Bold toolbar button (Figure 3a).

Format columns

The columns are now labelled, but the data do not line up very well with the headings: this will look very odd, especially when the sheet is printed.

- Centre the whole of column A by clicking on the A button at the top of the column and then using the Centred toolbar button (Figure 3b). Do the same with column B.

(a) 

(b) 

Figure 3 (a) The bold button and (b) the align centre button.

Column C contains numbers, and formatting these as centred probably isn't a good idea – in particular the decimal points won't line up! You can improve the appearance of the numerical data by telling StarOffice to display a fixed number of decimal places.

- Highlight column C and select Format | Cells ... On the Numbers tab, choose 1 decimal place (Figure 4).

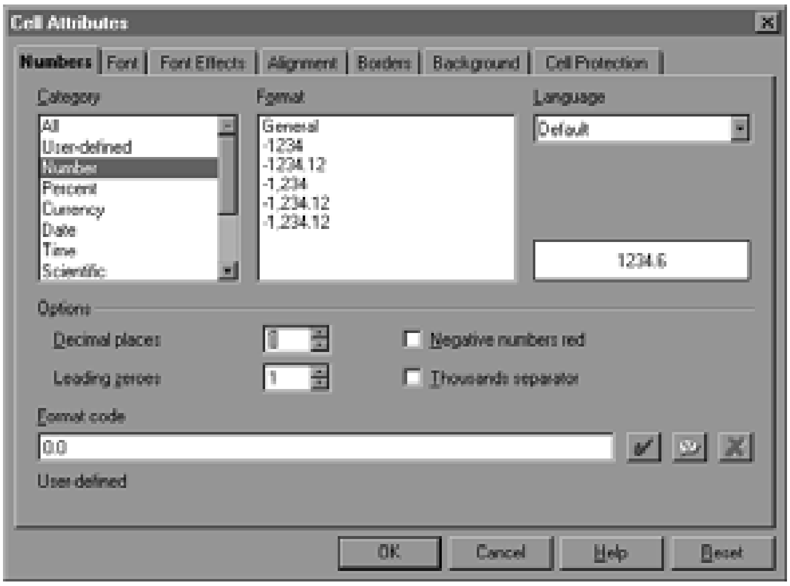


Figure 4 The cell attributes dialog box.

You may want to experiment with the formatting commands to present the data in a way that you like.

> Now would be a good time to *save* your work before going on to make more changes. As you continue to work through this activity remember to save your work regularly.

Calculations

(Refer to the *Using Spreadsheets* guide for further instructions on entering formulae.)

There are sunspot numbers for every month, but the Year column in your sheet only contains an entry in every twelfth cell. The Month columns contain data in the form of labels – that is, text rather than numbers.

In order to plot a graph of sunspot activity against the year we need a year value for each data point. A good way to do this is to combine the year and month to give a single numerical value (i.e. a decimal fraction of a year) that we can use for plotting.

First you need to make space to hold the new values by inserting a column.

- Highlight column C by clicking on the C button at the top. Then, keeping the mouse pointer over the C button, right-click and select Insert Columns. A new column C will be inserted, and the Sunspot number column moves to the right.
- Now go to cell C5 and enter the value ‘1953.0’. This is the starting point for the year calculations.
- In the cell beneath this enter the formula: ‘=C5+1/12’ and press Enter. The result of this is the value 1953.08 and this should appear in the cell. (Notice that if you select the cell again, the formula itself appears in the input line and you can edit it there.)

The formula must now be replicated down the whole column, and this can be done by dragging.

- Select cell C6 (the one that contains the formula). Now click on the little black square in the bottom right-hand corner of the cell and drag down to row 580 (drag down past the lowest visible cell and keep the mouse button held down while the sheet scrolls past).

This will replicate the formula all the way down the column: each cell will calculate a value 1/12 of a year (i.e. one month) more than the cell above. You now have a column containing decimal year values, from 1953.0 (January 1953) to 2000.92 (December 2000).

You may want to format this column to show two decimal places so that the whole years line up with the fractional years. You'll also want to give the column a heading: 'Decimal year', for example. (If necessary you can adjust the column width by dragging the boundary between column headings.)

Create chart

(Refer to the *Using Spreadsheets* guide for further instructions on creating and formatting charts.)

The data in columns C and D can now be used to plot a chart of sunspot number against the year. Highlight both columns by clicking on cell C5 and dragging all the way down and across to cell D580. From the main menu select Insert | Chart ...

- A box labelled AutoFormat Chart will appear. You don't need to change anything here, so select Next >> to move onto the next step.
- From the Choose a chart type options select XY Chart (Figure 5a), followed by Next >> to move onto the next step.
- From the Choose a variant options, select Lines Only (Figure 5b), followed by Next >> to move onto the next step. (Note that while going through these steps you can always press Back to go to an earlier step if you need to correct something.)
- Finally, in AutoFormat Chart make the following changes:

  The tick-box next to Legend should be cleared (i.e. without a tick).

  Make sure the X Axis and Y axis tick-boxes are ticked – this will cause the axis titles to be displayed.

  Insert the text for titles as follows:

Chart title:	Sunspot number
Axis title / X Axis:	Year
Axis title / Y Axis:	Sunspot number

- Finally, press the Create button – this will draw the chart.

(a) (b)

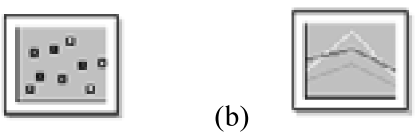


Figure 5 (a) The XY chart button and (b) the lines only button.

The chart will appear – usually at the top of the spreadsheet, so it is likely that you will have to scroll back up to the top of the sheet to see it.

Question 1

On the basis of the chart that you have just produced give a qualitative description of the behaviour of sunspot number over the period 1953–2000.

Question 2

Are there any aspects of the way in which the chart is displayed that could be improved to better show the behaviour of the sunspot number with time?

Formatting the chart

Having created the chart you will probably want to improve the way in which it displays these data, and maybe tidy it up to make it visually more appealing. This can be done by changing the *formatting*. In order to make changes the chart must be *selected*: there are two different levels of selection, signified by different borders around the chart:

- To resize, move or delete the chart: single click; the chart has green selection handles
- To edit or format the chart: double-click; the chart has grey border and small black squares
- To deselect the chart: click on any other cell in the spreadsheet.

Note that to swap between the 'resize, move, delete' selection and the 'edit, format' selection it is necessary to deselect the chart, before selecting it again.

The first thing that you are likely to want to do is to resize the chart to make it larger. To do this select it by single clicking and then dragging one of the green selection handles as required.

To change other aspects of the appearance of the chart you will need to make sure that the chart is selected for formatting (grey border and black squares).

There are many different things that you can do to change the appearance of your chart. Rather than describing all these the notes here give an example of how you could change one aspect of the chart – namely the appearance of the horizontal axis (X-axis). Other parts of the chart can be altered in similar ways and it is recommended that, if you have time, you should find out by experiment how to make other changes. (Always remember to save a copy of your file so that you can start again if the formatting ends up in a mess.)

If we wanted to make sure that the horizontal axes has tick marks for every year, and is labelled every ten years, we could make changes as follows:

- Select Format | Axis | X-Axis from the main menu.
- Select the Scale tab, then turn off the Automatic check boxes for Major interval and Minor interval.
- Set the value for the Major interval to 10: this will display a label every ten years.
- Set the value for the Minor interval to 1, then under the Tick-marks heading click on the tick-box labelled inner.

- While this box is open you can improve the display of numbers by clicking the Numbers tab, deselect the Source format option and then select 0 decimal places. This will make the years display as ‘1960’ instead of ‘1960.0’ and so on.
- Click on ‘OK’ when you are satisfied with the appearance of the axis.

You can change the formatting of just about any element of the graph by double-clicking on the part you want to change. As you move the mouse pointer over the chart a small label will appear telling you which item will be modified (you may need to be quite precise with the mouse to select the item you want!). In this way you can change the colour of the line plotted, add or remove background shading, gridlines and so on.

If you want to re-apply any of the chart type selections or titles choose Format | AutoFormat... from the main menu; this will take you through the AutoFormat Chart steps again.

Experiment with the various formatting options until you are happy with the appearance of your graph.

Printing the chart

Before printing your chart you should deselect it by clicking on any cell on the spreadsheet.

Experiment with the page layout to get the titles, chart and the first lines of data onto one page (you will probably want to print in landscape mode – to do this, select the menu item Format | Page then click on the Page tab, and then select the Landscape button).

Select File | Page Preview... from the main menu to preview exactly what will be printed.

You should aim to get a display similar to that shown in Figure 6 – you will probably need to reposition and resize the chart to make sure it fits onto the printed page.

Don’t forget that the sheet contains over five hundred rows of sunspot data: be careful to select Page 1 only when printing – otherwise you may get 16 pages of printout!

Save your final spreadsheet so that you can refer to it again later.

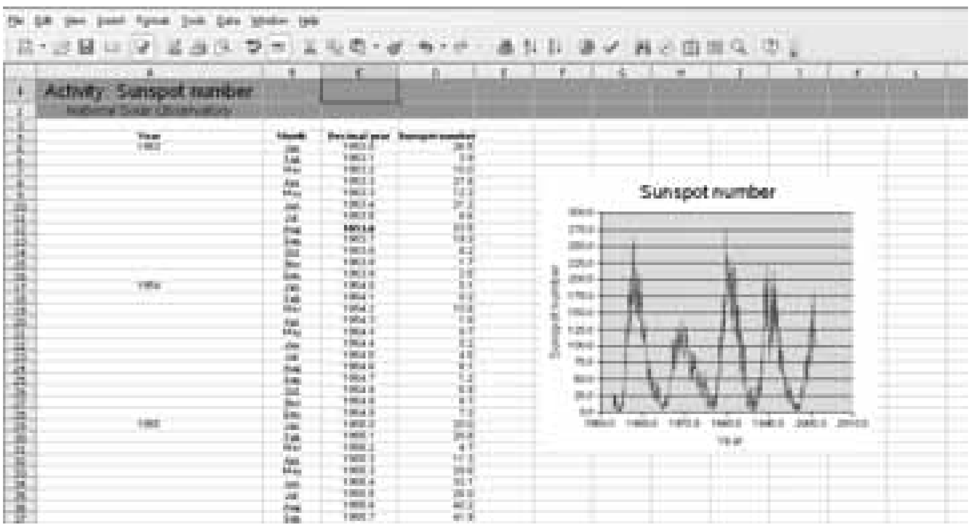


Figure 6 The sunspot number chart prior to printing.

The period of the sunspot cycle

You should now have a good representation of the sunspot number data for the period 1953–2000. The final part of this activity involves measuring the period of the sunspot cycle from the chart that you have produced.

Question 3

Give two different ways in which you could estimate the period of the sunspot cycle. For each method that you think of describe any advantages or disadvantages that it may have.

As described in the answer to Question 3, a good approach to measuring the period would be to measure the time between the first and last minimum of sunspot number and then to divide by the number of cycles. This is the approach that we will adopt here.

Question 4

(a) From your chart, estimate the date at which the first and last displayed solar minimum occurred.

(b) Hence calculate a value for the period of the solar cycle. (The calculation of the uncertainty in this result is described in the Question 4 answer below.)

Answers to questions

Question 1

The chart for 1953–2000 shows that the sunspot number changes with an approximately periodic variability. Within each cycle the sunspot number varies from a minimum to a maximum and then returns to a minimum again over a period of about ten years or so. However the variation does not repeat perfectly from cycle to cycle, and it is clear that the maximum value of sunspot number differs between cycles. The sunspot number also shows erratic variation, which seems to occur on a much shorter timescale than the period of the cycle.

Question 2

The answer to this question is somewhat subjective, but it is likely that the chart that is initially produced is rather small. Furthermore the default chart does not make best use of the available drawing area as it tends to extend the horizontal axis to a value that is substantially beyond the last data point. (Details on how to change these aspects of the chart are described in the notes after Question 2.)

Question 3

There are several ways of estimating the period from data such as those shown in the chart. Rather than describe all options in detail, here we outline the general principles behind the measurement of the period. You should be able to relate your two methods to these general approaches.

It is necessary to measure the time interval between repeating features such as the maxima or minima of sunspot number. However, the choice of feature will have an effect on the precision of the measurement. It is clear from the chart that the

time of sunspot maximum is more poorly defined than the time of sunspot minimum. Thus measurements based on estimating the times of the minima are likely to have smaller uncertainties than those based on the maxima.

The second point to consider is the number of intervals that are used in the measurement. One approach could be to measure the time taken for one cycle to repeat – so for instance you could measure the time interval between the first and second minimum. This has the disadvantage that it only uses a small amount of the information provided. This approach could be extended by finding the average interval between all successive cycles (i.e. between first and second, second and third, third and fourth). However the problem with measuring over a single cycle is that any uncertainty in determining the time of the minimum is a substantial fraction of the time being measured. This uncertainty can be reduced by measuring the time taken for several cycles to repeat, then dividing by the number of cycles.

Question 4

(a) The data at the earliest dates shown on the chart (around 1953) are close to a minimum, but the coverage of the minimum is not sufficient to enable a reasonable estimate to be made of when it occurred. The first minimum that is seen in its entirety is the one around 1964, and it is better to use this as the first minimum. The date of the last minimum appears to be about 1996.

(b) Since there are three cycles between 1964 and 1996, the period is given by

$P = (1996 - 1964)/3 = 10.7$ years

So the period of the sunspot number as determined from these data would be 10.7 years.

The uncertainty in the period that you determined in Question 4 can be found as follows. If a quantity z is found by subtracting one number y from another x (i.e. $z = x - y$), then the uncertainty in z is related to the uncertainties in x and y by

$$\Delta z = \sqrt{\Delta x^2 + \Delta y^2}$$

(Note that the symbol Δ is used to indicate the uncertainty in a quantity, so, for instance, Δx is the uncertainty in x.)

For the sake of this example we will use the following values:

- Time of first minimum: 1964 (note the minimum around 1954 cannot be established from these data as the coverage only starts in 1953).
- Time of last minimum: 1996
- Number of cycles between these minima: 3

This yields a value for the period P of 10.7 years (see the answer to Question 4).

The time of any minimum can be estimated to within ±2 years, so the uncertainty in the time interval between the first and last minimum is

$$\Delta t = \sqrt{2^2 + 2^2} = \sqrt{8} = 2.8 \text{ years}$$

This represents the uncertainty in the time for three complete cycles, so the uncertainty in the period is one-third of this value

$\Delta P = (2.8 \text{ years})/3 = 0.9$ years

So the uncertainty in the period that would be obtained from the analysis of the chart data would be ±0.9 years, and the final result can be quoted is that these data yield a value for the period of (10.7 ± 0.9) years.